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BRACKISH WATER SOURCES
FOR IRRIGATION

ALONG THE EASTERN SEABOARD
OF THE UNITED STATES

PRODUCTION RESEARCH REPORT NO. 61

Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE
In Cooperation With
Virginia Truck Experiment Station

CONTENTS

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The use of supplemental irrigation along the eastern seaboard has increased rapidly during the past few years. This practice has been beneficial not only during droughty years, but also during years of average rainfall when the amount of water has been limited at a critical stage of crop growth. One of the major factors limiting the use of supplemental irrigation to coastal areas has been the lack of an adequate supply of good quality water.

The use of wells for supplemental irrigation in many areas has been unsuitable, because shallow wells produced an inadequate volume and deep wells were frequently brackish, or saline. The use of rivers and streams has also been questionable because of a possible salinity hazard. In order to provide additional sources of water, farmers have been building seepage ponds and other water source facilities. Where these have been located adjacent to marshy areas, there is a possibility of saline contamination. Thus, in many areas, a salinity problem has arisen.

The utilization of brackish water for supplemental irrigation is not new. Prior to and after the Civil War, planters along the southeastern coast of the United States used the coastal marsh areas for the growing of rice and some used brackish water for irrigation. Later, farmers along the eastern seaboard used brackish water with varying results. Very often detrimental effects attributed to brackish water irrigation were due to improper use of this water and, in some instances, to some cause completely unrelated to the water used. As a result, a project was established at Norfolk, Va., in 1955 for the purpose of determining the factors involved in the use of brackish water for supplemental irrigation in humid regions.

As a first step toward this objective, a survey was established to determine what sources of brackish water were being used and how these waters varied seasonally in both salt concentration and composition. The following report presents a summary of data collected over a 4-year period.

For the purpose of this discussion, the term "brackish water" will refer to saline water.

SOURCES OF BRACKISH WATER

Tidal streams and creeks provide one of the main sources of brackish water along the eastern seaboard. Some of these can be used for irrigation, but they may be hazardous because the salt concentration at any location is subject to wide seasonal as well as daily tidal fluctuations. Furthermore, these creeks and streams are not accessible to all

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who might require water for irrigation. As a result, farmers have looked for other sources of irrigation water. With the help of the Soil Conservation Service they have constructed many types of water supply and storage facilities.

The legal aspects relative to the use of each type of brackish water source should be investigated before farmers develop facilities for using the water.

Seepage Ponds

Seepage ponds are excavations dug in areas where recharge is dependent upon subsurface seepage, surface runoff, and precipitation. On the Eastern Shore of Virginia, these seepage ponds are occasionally dug adjacent to the coast; usually with one side bordering along the coastal marsh and the rest in the upland. These ponds are dug 6 to 8 feet deep and sufficiently large in area to meet the irrigation requirements. It was found initially that this type of pond was usually quite high in salt concentration and, unless pumped and flushed, would take 2 or 3 years before the salt concentration dropped to a safe level for irrigation. With heavy pumping, seepage from the brackish marshes may occur, causing recontamination of the water. Because of this, it has been found desirable to select sites farther inland to establish seepage ponds.

Dammed Tidal Inlets

Dammed tidal inlets are used extensively along the eastern seaboard (fig. 1). An inlet, as referred to in this study, may be an old

FIGURE 1.—A dammed tidal inlet near Bridgeton, N.J.

drainage channel that extends to the marsh or it may be a marshy area that extends inland. The site for the dam is selected to give the greatest storage area for impounding the water. The dam should be constructed high enough to prevent overtopping by high tides. At locations where the storage area is not sufficiently large, the inlet is excavated to give the desired capacity. When filled initially, most of these inlets are quite high in salt concentration because brackish tides have inundated the areas periodically for years. It is common practice to pump the water from these inlets when they first fill up in order to remove the highly saline water. Usually one pumping will remove most of the salinity. Then, through surface runoff and seepage, the salt concentration will drop gradually over a period of 2 to 3 years.

Wells and Storage Ponds

Wells have not proved to be an adequate source of irrigation water along the eastern seaboard. The limited data available on wells indicate that in many areas good water can be obtained from shallow wells but the volume is limited. A greater volume can be obtained by going deeper, but the salt concentration frequently increased with depth. In the area around Charleston, S.C., where seepage ponds have not been satisfactory, the farmers use banks of wells. Water is pumped from these banks of wells into storage reservoirs where it is held until used for irrigation (fig. 2).

FIGURE 2.—Water being pumped from a well into a storage pond near Charleston, S.C.

The well-storage pond system is used primarily in the vicinity of Charleston, S.C., where there are many islands surrounded by channels that are high in salt concentration. For this reason, the usual seepage-type pond and dammed inlet are not practical, so farmers use the storage-type pond. The size of the ponds depends upon the size of the area the farmer wishes to irrigate. The storage ponds are excavated to a depth of 6 to 10 feet, and the spoil is built up around them to give additional storage capacity. The ponds are usually 40 to 100 feet wide and several hundred feet long and so designed that the farmer can put on one application of water without refilling the reservoir. A farmer may have 2 to 3 reservoirs of this type spaced around his farm. Another situation in which this type of pond could be used to advantage is in areas where the rivers are affected by tides. During periods of low salt concentration, water from the river could be used to fill the ponds.

Diked Drainage Areas and Ditches

The diked drainage area was observed in the vicinity of Bridgeton, N.J., but this type of storage is not common (fig. 3). It consists of a ditch dug between the tidal marsh and the upland. It is so designed that it can serve as a drainage ditch during the wet periods and as a source of irrigation water during dry periods. The spoil from the ditch is thrown up on the marsh side to protect the ditch and adjacent area from high tides. The site included in this survey has not been too satisfactory, because the concentration of salts has

Figure 3.—A diked drainage ditch near Bridgeton, N.J.

been extremely variable and unpredictable. The cause of this variation has not been determined.

Tidal Marshes

In some areas farmers have utilized diked portions of tidal marshes as reservoirs. These would serve as a storage facility for drainage water from adjacent areas and as a source of irrigation water, in a manner similar to that described for the diked drainage area. Pumping water directly from a tidal marsh has also been observed, but is not common practice. An example is shown in fig. 4, where a farmer made a small excavation in the marsh from which water could be pumped.

FIGURE 4.—Pumping brackish water directly from a tidal marsh near Bridgeton, N.J.

Rivers and Streams

Rivers and streams make excellent sources of irrigation water when they are nearby. When these sources are subject to tidal contamination, the water should be used with caution. The salinity level of rivers and streams so affected will also be influenced by rainfall and runoff from the surrounding watershed. An important consideration in the use of these waters will be the location of the fall line. Water above this point would be safe to use at any time, while below the fall line the salt concentration might be too high for irrigation purposes.

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To utilize these streams effectively, a survey of the effect of tidal changes on the salt concentration should be made at various points. During periods when the salt concentration is sufficiently low, water could be used directly for irrigation or pumped into a reservoir area. It is doubtful whether or not wind tides would appreciably affect the salinity level except, perhaps, at the mouths of rivers.

Bays and Sounds

Bays and sounds along the eastern seaboard are a potential source of irrigation water (fig. 5). These bodies of water frequently extend inland and are available to large agricultural areas. The level of salinity in these waters is determined by the influence of tides and the volume of fresh water flowing in from adjacent rivers and streams. The influence of wind tides would be determined by the size and location of the sea opening. Since the level of salinity of these waters may vary considerably, they should be tested just prior to irrigating.

FIGURE 5.—Pumping water directly from Currituck Sound in North Carolina.

SURVEY SAMPLING AND ANALYTICAL PROCEDURES

Sampling Sites

The coastal area involved in this survey extended from New Jersey to South Carolina. Although this area does not represent the total extent of the brackish water problem, it contained a wide variety of

water supply and storage facilities for study. The following four locations within this area were chosen for sampling sites: Bridgeton, N.J.; Accomac, Va.; Currituck, N.C.; and Charleston, S.C. The types of problems encountered varied considerably among these four locations. Representative brackish water supply and storage facilities were selected for sampling with the aid of the Soil Conservation Service personnel in each area. Most sites were selected because they constituted a salinity problem. For this reason, a monthly water sampling schedule was planned to permit an evaluation of seasonal changes in salt concentration and composition.

Sampling Procedures

Samples from the various water sources were collected. A water sampler consisting of an 8- to 10-foot jointed bamboo rod marked in feet was used. A piece of plumber strap was attached to the lower end of the rod and formed into a circle so that a 4-ounce glass or plastic bottle could be clamped in place. A rubber stopper, to which a cord was attached, was placed in the neck of the bottle. The bottle was then lowered to the desired depth, the stopper pulled, and the bottle allowed to fill. In this manner, little or no mixing occurred in taking the sample.

Samples were collected from two locations and two depths for each pond site selected. The locations usually selected were the dam or spillway and the pumping station at the opposite end of the pond. Only one sample from each location was taken from rivers, streams, bays, and sounds. Water samples were collected by the local Soil Conservation Service personnel and sent into the Norfolk laboratory of the Agricultural Research Service for analysis once a month. Samples were collected approximately the same time each month.

Analytical Procedures

The quality of water used has an important influence on crop results that may be expected from irrigation. It has been found that two of the most important factors in determining the quality of the water are the total salt concentration and the amount of sodium and its relation to other cations. In the West, boron, carbonates, and bicarbonates are also important factors in determining water quality, but there is no evidence of this being a problem along the eastern seaboard.

Most analytical procedures used were those described by the U.S. Salinity Laboratory Staff.[2] The total soluble salt concentration was estimated by determining the electrical conductivity of the solution. Salt concentration of water in this discussion will be expressed in terms of its electrical conductivity (EC in mmhos/cm.).[3] The pH of the water sample was determined with a Beckman Model G glass electrode potentiometer. Calcium plus magnesium was determined by titration with EDTA, with Erichrome Black T used as an indicator. Calcium was determined by titration with EDTA, with Cal

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[2] U.S. Salinity Laboratory Staff. diagnosis and improvement of saline and alkali soils. U.S. Dept. Agr., Agr. Handb. 60, 160 pp., illus. 1954.

[3] An EC value of 1 mmho per cm. is approximately equivalent to 640 parts per million of salts.

Ver II used as an indicator. Magnesium was determined by differ-
ence. Sodium and potassium were determined with a Beckman
Model B flame photometer, which was standardized with solutions
containing interfering ions in the approximate ratios in which they
occurred in the water samples. Chlorides were determined volumet-
rically by titration with mercuric nitrate, with diphenylcarbazone
used as an indicator. Carbonates and bicarbonates were determined
on a single aliquot by titrating with $0.01N$ H_2SO_4. Carbonates were
determined by titrating to a phenolphthalein end point, and bicarbon-
ates were determined by titrating to the methyl orange end point.
Sulfates were determined by an EDTA titration procedure.[4]

RESULTS OF SURVEY

During the period of this survey large quantities of data were col-
lected. For the purpose of this report, only selected data are pre-
sented that illustrate specific problems. Detailed chemical analyses
of water samples are attached as an appendix.

Salinity Data From Various Sources

Farm Ponds

A group of samples was selected to illustrate fluctuations in salinity
encountered in farm ponds (table 1). The Beasley pond near
Churchland, Va., represents a dammed tidal inlet where the dam and
spillway were not built sufficiently high to protect the pond from ex-
cessively high tides. This pond is normally low in salinity. Early
in 1957, the salt concentration was quite low. In September 1957, the
dam was overtopped by high tides during a storm and the level of
salinity increased. Through normal runoff and seepage from the sur-
rounding areas, the salt concentration was gradually reduced to a low
level by January 1958. The salinity level remained low until October
1958, when the dam was again inundated by high tides. Again,
through dilution, the electrical conductivity dropped to below 1.0
mmho per cm. by May 1959.

The dam and spillway were then built to sufficient height to protect
them from overtopping by high tides. Since that time this pond has
not been inundated. This example shows why it is essential that
dammed structures be built sufficiently high to protect ponds from
contamination by tides.

The control of rodents is frequently a problem in protecting water-
retaining structures used in ponds or dammed tidal inlets. During
this survey there have been several occasions where a rise in salt con-
centration of impounded water has occurred, and the cause traced to
muskrat burrows penetrating the dam. An example of this is shown
in the data taken from the Fitchette pond on the Eastern Shore of
Virginia. During 1957, the salt concentration rose from an EC value
of 0.6 to over 2 mmhos per cm. This increase was caused by rodent
burrows. During 1958 the rodents were kept under control, but in
1959 the salinity level of the pond again rose from an EC value of 0.6

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[4] JACKSON, M. W. SOIL CHEMICAL ANALYSIS. 498 pp., illus. Prentice Hall,
Inc., Englewood Cliffs, N.J.

TABLE 1.—*Salt content of various types of farm ponds and ditches (electrical conductivity in millimhos per centimeter)*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Beasley pond, Churchland, Va.												
1957	1.50	0.60	0.52	0.51	0.52	0.61	0.61	0.81	4.70	5.00	5.30	1.72
1958	.79	.67	.36	.50	.41	.47	.48	.36	.37	19.90	12.00	9.80
1959	3.70	2.70	1.69	.90	.85			.70	.70	.33	.50	.52
1960	.52	.49	.58		.57		.53	.34	.78	.70		.58
Fitchette pond, Eastern Shore, Va.												
1957	1.60	0.90	0.60	0.60	1.72	1.99	2.02	2.25	2.16	0.90	0.78	0.50
1958	.60	.55	.50	.54	.45	.71	.48	.33	.48	.52	.59	.53
1959	.62		1.44	.68	1.29	.90	1.43	8.90	10.30	5.20	4.50	6.60
1960	7.50	2.15	.91	1.50	1.88	4.80	3.45	1.05		6.50	6.40	8.40
Bowker pond, Bridgeton, N.J.												
1957	5.40	4.20	4.30	3.80		4.00	5.12		7.60	8.25		6.40
1958		2.03	2.02	1.99	2.05	2.05	3.85	3.07	2.62	2.35	2.35	2.35
1959	1.30	1.29	1.25	1.20	1.20	1.21	1.46	1.38	1.45	1.40	1.36	1.30
1960							1.31	.89	.67	.66	.81	.78
Dix Bros. ditch, Bridgeton, N.J.												
1957	6.30	10.00					15.00		23.90	27.90		7.50
1958		2.80	3.80	4.40	4.75	10.30	8.00	8.75	11.80	9.00	4.30	10.20
1959	5.50	6.50	5.00	5.50		4.50	2.85	5.02	6.75	4.60	6.50	4.50
1960			13.30	6.60	12.50	15.00	11.70	16.00	3.60	10.20	12.00	3.90
Ames pond, Eastern Shore, Va.												
1959	14.00	16.00	15.00	6.90	10.00	11.00	12.00	12.00	13.20	12.00	14.00	14.00
1960		12.40		14.00	15.00	13.25	15.00	15.00		30.00	31.50	32.40

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to 10.0 mmhos per cm. as a result of rodent damage. This pond was contaminated in a similar manner during 1960. Another example was observed in a pond near Churchland, Va., where a blowout of a dam was attributed to muskrat burrows. It is important, therefore, that rodent control be considered in protecting water-storage areas.

Data collected in this study show that it takes several years for the salt concentration of a pond to drop to a usable level when the initial salt concentration is quite high. An example of this is shown in the data from the Bowker pond near Bridgeton, N.J. The initial electrical conductivity of the water in this pond during September 1957 was 7.6 mmhos per cm. The conductivity was gradually reduced over a period of time by dilution with fresh water seepage and runoff. During the latter part of 1960, the conductivity of the water was reduced to below 1.0 mmho per cm., and samples collected in 1961 show a still further drop. It is apparent that, with an initial high level of salinity, it will take at least 2 to 3 years before ponded water is sufficiently low in salt concentration that it may be safely used on all crops.

Drainage ditches are occasionally used as a source of irrigation water. Samples were collected from an installation of this type from the Dix Bros. farm near Bridgeton, N.J. This diked ditch bordered on a tidal marsh. The salt concentration of water in this ditch has remained high throughout the survey period. No definite cause can be ascertained for the variability and the high salinity values obtained. It is possible that it is the result of seepage under a hydrostatic head from the adjacent marsh.

The Ames pond is a dammed tidal inlet. The high salinity values obtained after 2 years of sampling indicate a faulty structure.

Bays and Sounds

In some areas bays and sounds may serve as a source of irrigation water for a large agricultural area. An example of this is Currituck Peninsula in North Carolina which is bounded on the east by Currituck Sound and on the west by Albemarle Sound. Sampling sites were established for these two sounds midpoint in the peninsula and at the southern tip (Point Harbor) where these two bodies of water join Pamlico Sound. Data are presented in table 2.

Samples collected from Currituck Sound (Currituck, N.C.) were low in salt content throughout the period of the survey. There was no increase in the salinity of this body of water even when a hurricane passed through the area in September 1960. This is a good source of irrigation water if the necessary precautions are observed when so used.

Albemarle Sound is a larger body of water, and the salt concentration fluctuated more than it did for Currituck Sound. Conductivity values of samples taken at Jarvisburg, N.C., ranged from a low of 0.70 mmho per cm. in July 1958 to a high of 5.40 mmhos per cm. in November 1960. Aside from the fact that the highest salt concentrations were observed during the months of November, December, and January, there was no general trend to the fluctuations. The data indicate that this water could have been used for irrigation with minimum precautions during June, July, and August 1958. During the same months of 1959 and 1960, this water could also have been used, but with certain restrictions.

TABLE 2.—*Salt content of Albemarle and Currituck Sounds, N.C. (electrical conductivity in millimhos per centimeter)*

| Year | Sampling date | | | | | | | | | | | |
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Currituck Sound, Currituck, N.C.												
1958				0.78	0.48	0.76	0.93	1.10	1.03	0.58	1.00	1.58
1959	1.58	0.66	0.94	1.08	1.15	1.45	1.30	1.63	1.80	1.50	2.20	1.49
1960	1.51	.63	.91	.83	1.00	.86	1.05	.71	.40	.71	.90	1.22
Albemarle Sound, Jarvisburg, N.C.												
1958				1.10	1.10	0.80	0.70	0.70	0.53	1.21	5.02	5.25
1959	5.25	4.90	4.00	2.95	3.40	2.20	4.75	2.85	2.62	5.00	4.45	4.00
1960	2.71	1.60	1.20	.92	1.13	2.50	2.80	2.55	2.99	4.40	5.40	4.50
Point Harbor, N.C.												
1958				2.58	1.65	0.70	1.08	2.28	1.41	2.25	6.00	7.50
1959	7.50	4.95	4.25	6.75	4.50	4.40	6.00	5.20	3.50	6.50	6.10	4.60
1960	3.60	2.16	.90	.89	4.00	7.50	4.40	3.75	3.30	4.70	6.00	6.30

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The salt concentration of the water at Point Harbor, N.C. is probably affected by wind tides from Pamlico Sound. Since Pamlico Sound is east and southeast of Point Harbor, it is possible that heavy winds from the southeast quadrant might push the more saline waters of Pamlico Sound back to this point. This, together with fluctuations in the salinity of contributing bodies of water resulting from rainfall and runoff, probably accounts for the observed conductivity values ranging from 0.70 to 7.50 mmhos per cm.

In order to determine the effect of tides on salinity in this area, samples were collected at hourly intervals from the Wright Memorial Bridge below Point Harbor for the period from 1:00 a.m. to noon on March 31, 1961. Conductivity values for these samples did not vary more than two-tenths from 2.6 mmhos per cm. Apparently there was no effect of tides at this point.

Rivers and Streams

Samples of rivers and streams subject to tidal effects were collected from the area around Bridgeton, N.J., and the Eastern Shore of Virginia and from Charleston, S.C. To illustrate the type of fluctuations encountered, the data from several rivers in the Bridgeton, N.J., area are presented in table 3. Samples were collected without regard to tidal stage during the months of March, June, September, and December of the years 1958, 1959, and 1960. Two sampling sites were selected for each river: the No. 2 site is located the farthest inland. The data show large differences in salinity between sites for a given river. The level of salinity at a given site also varied with the sampling date. In many instances, differences in salinity of samples from a given site were quite large.

In order to estimate the contribution of tidal effects to the variation in salinity levels of these rivers, samples were collected from the Cohansey and Nantuxant Rivers in August 1961. The data (table 4) show that the conductivity of water from the Cohansey River varied from 19.0 mmhos per cm. at high tide to 8.5 mmhos per cm. at low tide, and remained at the latter level for over 1½ hours. Conductivity values for the Nantuxant River ranged from 18.4 mmhos per cm. at high tide to 0.8 mmho per cm. at low tide. In the Nantuxant River salinity levels remained low enough for agricultural use for a period of over 5 hours. Data from these two rivers indicate that more information of this type is necessary to determine the potentialities of various tide-affected rivers and streams as sources of irrigation water.

Samples of water from other rivers and streams in Virginia and South Carolina were also collected. Analyses of these samples for the most part have shown that the salt content was too high for the water to be applied to agricultural uses. Of the streams sampled on the Eastern Shore of Virginia, those in which the salt concentration was sufficiently low were too small to be of any consequence for use as an irrigation source. Some of the data obtained from these sources are shown in tables 7 and 8 of the appendix.

TABLE 3.—*Salt content of four rivers in southern New Jersey (electrical conductivity in millimhos per centimeter)*

River or creek and location No.[1]	Sampling date											
	1958				1959				1960			
	Mar.	June	Sept.	Dec.	Mar.	June	Sept.	Dec.	Mar.	June	Sept.	Dec.
Cohansey River:												
No. 1		8.40	27.90	10.00	12.00	6.50	26.50	11.50	30.00	15.00	6.20	27.00
No. 2		2.90	6.00	2.75	4.20	24.00	6.25	3.60	5.25	5.50	1.18	4.70
Maurice River:												
No. 1		8.10	6.10	2.80	10.60		5.48	2.04	5.02	4.00	.10	6.60
No. 2		2.40	.67	.10	.76	1.82	.68	.10	.41	.78	.18	1.29
Dividing Creek:												
No. 1		8.00	12.20	4.75	16.50	14.00	11.00	2.70	6.40	5.60	.86	17.50
No. 2		5.20	7.50	1.82	10.00	12.00	7.50	1.72	2.46	3.80	.59	7.60
Nantuxant River:												
No. 1		22.00	28.40	24.00	25.50	25.50	30.00	14.50	25.00	15.00	10.20	32.00
No. 2		21.00	10.20	1.06	12.00	13.50	1.23	5.40	5.68	1.48	.80	20.00

[1] Location No. 2 is located farther inland than first location.

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Sampling time	Cohansey River		Nantuxant River	
	Height [1]	Salinity	Height [1]	Salinity
	Ft.	*Mmhos/cm.*	*Ft.*	*Mmhos/cm.*
8:30 a.m	8. 0	17. 0		
9:00	8. 0	18. 0	7. 6	18. 0
9:30	7. 9	19. 0	7. 6	18. 4
10:00	7. 7	17. 0	7. 5	18. 0
10:30	7. 1	17. 0	7. 3	14. 5
11:00	6. 8	15. 0	7. 1	13. 5
11:30	6. 2	13. 5	6. 9	11. 4
12:00 noon	5. 8	12. 0	6. 6	5. 8
12:30 p.m	5. 2	11. 5	6. 3	5. 0
1:00	4. 6	10. 8	6. 0	2. 9
1:30	4. 0	10. 2	5. 6	1. 9
2:00	3. 6	10. 0	5. 2	1. 1
2:30	2. 1	8. 5	4. 8	. 9
3:00	2. 6	8. 5	4. 6	. 9
3:30	2. 5	8. 5	4. 5	. 9
4:00	3. 4	8. 5	4. 4	. 8
4:30	4. 2	9. 0	4. 4	. 8
5:00	4. 1	9. 4	4. 6	. 8
5:30	5. 8	10. 0		

[1] Height of tide in the Cohansey River was measured directly with a staff gage and recorded. Tidal height in the Nantuxant River was estimated by measuring down from a bridge to the water level and subtracting the reading from 10.

Wells

In many areas along the eastern seaboard, some wells are being used as a source of irrigation water. As previously pointed out, shallow wells may yield good quality water but be inadequate in volume. Deep wells may have adequate volume but may yield poor quality water as a result of salt water intrusion in one of the intercepted aquifers. Although little data on wells were obtained during this survey, the effect of salt intrusion is demonstrated in logs of test wells taken by the Atlantic City Water Works (table 5). This variation in salinity with depth is an example of what may be encountered when digging wells in coastal areas.

TABLE 5.—*Chloride content of water samples from test wells in New Jersey* [1]

Well T–13		Well T–7	
Depth below surface	Chlorides	Depth below surface	Chlorides
Ft.	*P.p.m.*	*Ft.*	*P.p.m.*
12	4, 600	10	3, 900
26	3, 400	32	900
39	5, 500	50	200
44	6, 300	57	32
53	1, 200	69	3, 200
73	7, 300	77	5, 000

[1] Obtained from logs of Atlantic City Water Works.

Chemical Analyses of Water Samples

Since quality of water is determined by chemical composition as well as total concentration of salts, samples from the many sources were analyzed for both cation and anion content. Data from representative samples are presented in tables 7 to 12 in the appendix. In order to evaluate the relative constancy in composition of these samples, several were selected that covered a wide range in total salt concentration (table 6). When the individual cation concentration was calculated as a percentage of the total cation content, it was found that the composition was very similar to that of sea water for almost all samples. The percentages of calcium, magnesium, sodium, and potassium found in sea water are 3.3, 16.9, 77.9 and 1.9, respectively. The greatest deviations from sea water composition occurred when the electrical conductivity values dropped below 1.5 mmhos per cm. Subsequent analyses have confirmed this relationship.

The anion composition also closely resembled that of sea water except for the fact that the relative chloride content is sometimes slightly lower and the sulfate content slightly higher. There is no indication that either boron or bicarbonates are a problem in these waters.

The U.S. Salinity Laboratory, Riverside, Calif., has used the Sodium-Adsorption-Ratio (SAR) value as a measure of water quality.[5] It is defined as follows:

$$SAR = \frac{Na^+}{\sqrt{\dfrac{CA^{++} + Mg^{++}}{2}}}$$

when the concentrations are expressed as milliequivalents per liter of the respective ions. They have also derived a relationship between the SAR of a water sample and the Exchangeable-Sodium-Percentage (ESP) of a soil brought into equilibrium with that water. Although this relationship does not hold true for base unsaturated soils of the humid areas, the SAR of a given water will determine to a certain extent the relative amount of sodium that will be adsorbed by that soil. For waters of equal total salt content, one having a high SAR will be more hazardous than one having a low SAR value. For waters of identical relative cation composition, the SAR value decreases with decreasing total concentration. As most of the saline waters do have the same relative cation composition, the above relationship relating SAR and concentration may be used.

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[5] See footnote 2, p. 7.

TABLE 6.—*Relationship between brackish water analyses and sea water composition*

Owner or location and sample No.[1]	pH value	EC[2]	Cation-solution concentration and percentage of total cation content							
			Ca++		Mg++		Na+		K+	
			Meq./l.	Percent	Meq./l.	Percent	Meq./l.	Percent	Meq./l.	Percent
Eastern Shore of Virginia—May 15, 1958										
Tom Smith pond	7.47	1.78	1.43	9.00	2.81	17.70	11.25	71.70	0.35	2.20
George Ames pond	6.15	7.00	3.01	4.50	9.99	15.00	52.50	78.60	1.25	1.90
Jones Bros. Creek	7.08	35.00	10.60	3.30	55.20	17.10	252.00	77.90	5.60	1.70
Jenkins Bros. Creek	6.99	7.75	3.03	3.70	13.67	16.80	630.00	77.80	1.40	1.70
Bullboggar Creek, No. 1	6.70	6.90	2.38	3.40	12.12	17.10	55.00	77.70	1.30	1.80
Bullboggar Creek, No. 2	6.59	4.65	1.77	3.50	8.15	15.80	40.50	78.90	.90	1.80
Mosquito Creek	7.73	31.50	9.70	3.20	51.80	17.00	238.00	78.20	5.00	1.60
Currituck, N.C.—May 27, 1958										
Currituck Sound	6.48	0.48	0.46	9.50	0.66	13.70	2.75	57.10	0.95	19.70
Poplar Branch	6.60	.93	.71	9.20	1.32	17.00	5.55	71.70	.16	2.10
Dews Island	6.78	1.20	.74	7.10	1.78	17.00	7.70	73.70	.23	2.20
Albemarle Sound	7.03	1.10	.54	4.90	1.89	17.30	8.30	75.90	.21	1.90
Point Harbor	7.01	1.65	.74	5.40	2.35	17.10	10.40	75.70	.25	1.80
Bridgeton, N.J.—Apr. 30, 1958										
Wm. Bonham pond	3.29	2.80	2.02	8.90	4.48	19.80	15.60	69.10	0.50	2.20
N. Bowker pond	3.86	3.80	1.53	4.50	5.75	16.90	26.20	77.30	.43	1.30
Dix Bros. dike	6.54	4.40	1.83	4.60	7.27	18.30	30.00	75.40	.67	1.70
Cohansey River, No. 1	6.70	8.40	3.04	3.60	14.80	17.40	65.50	77.30	1.40	1.70
Cohansey River, No. 2	6.60	2.90	1.18	4.40	4.50	17.00	20.30	76.70	.51	1.90
Maurice River, No. 1	6.29	2.18	.84	3.80	3.64	16.70	17.00	77.50	.45	2.00
Maurice River, No. 2	6.18	.24	.23	11.80	.37	19.00	1.30	66.60	.05	2.60
Dividing Creek, No. 1	6.53	8.00	2.68	3.50	13.84	17.80	59.50	77.10	1.20	1.60
Dividing Creek, No. 2	6.40	5.20	1.72	3.50	8.64	17.30	38.50	77.50	.85	1.70
Nantuxant River, No. 1	6.79	22.00	5.70	3.30	30.50	17.50	135.00	77.50	2.90	1.70
Charleston, S.C.—May 29, 1958										
Stono River bridge	7.29	28.50	9.50	3.60	44.25	16.80	204.00	77.90	4.50	1.70
Dowhoo River	7.16	4.90	1.75	4.40	6.55	16.30	31.00	77.10	.90	2.20
Toogoodo River	7.76	25.50	12.00	3.60	57.50	17.40	254.00	77.30	5.60	1.70
Sea water composition	----	----	----	3.30	----	16.80	----	77.90	----	2.00

[1] Sample No. 2 is located farther inland than sample No. 1.
[2] Electrical conductivity is in millimhos per centimeter.

The SAR value of a solution can become a more useful criterion when a mathematical relationship between it and ESP can be established that takes into consideration the degree of base saturation of the soil. In order to facilitate the estimation of the SAR value for a water sample from its electrical conductivity, a graph relating EC and SAR was prepared by determining the conductivity value of several dilutions of synthetic sea water and their calculated SAR values (fig. 6). By means of this graph, the estimated SAR values of 30 water samples selected at random were determined. These estimated SAR values were plotted as a function of the SAR values calculated from the actual chemical composition of these waters
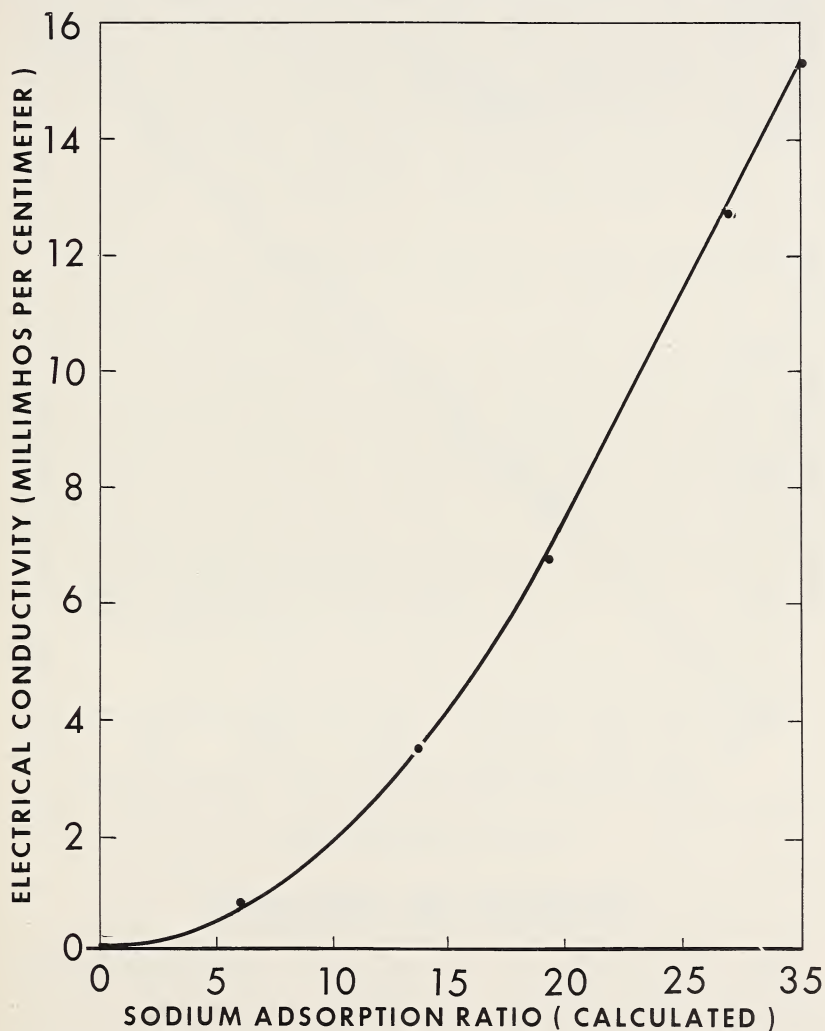
FIGURE 6.—Estimation of SAR values of a synthetic sea water from electrical conductivity determinations.

(fig. 7). A highly significant correlation was obtained. This relationship is useful only where the chemical composition of the saline water is known to have the same relative cation composition as sea water. Waters having EC values less than 1.5 mmhos per cm. have not been found to fall in this category.
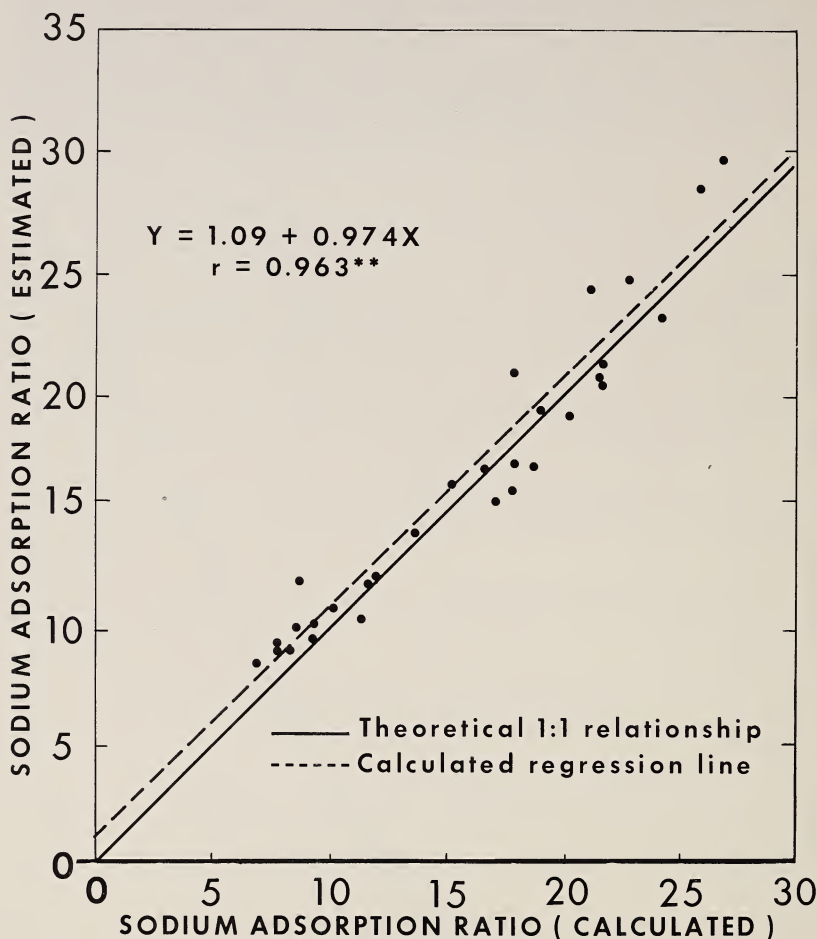
Figure 7.—Relation between calculated SAR values and those estimated from electrical conductivity values.

DISCUSSION AND CONCLUSIONS

With the increasing rate of urbanization and industrialization along the eastern seaboard, the shortage of good quality water is becoming more pronounced. The increased consumption of water in coastal areas is resulting in an encroachment of saline water in underground aquifers. Since many of the sources of water for agricultural use in coastal areas tend to be brackish, it is important

that additional information be obtained on factors affecting observed changes in salinity. Where these can be controlled, some means for doing this should be devised. Where no control is feasible, a plan for utilizing these waters when the salinity level is sufficiently low should be developed.

The successful use of these brackish waters depends upon a knowledge of the salt content at time of irrigation. Variations in the salinity of various water sources have been illustrated and the associated causative factors discussed.

Climate has a pronounced effect on the salt concentration of the various water sources. Rainfall is the predominant factor in determining the degree of dilution of brackish water in farm ponds and reservoirs through seepage and runoff. Rivers, streams, bays, and sounds are also influenced by rainfall insofar as they are diluted by fresh water from the adjacent watershed. During storms, however, unusually high tides may cause overtopping of dams in some farm ponds. High winds can also push highly saline waters close to the sea back into less saline adjacent bodies of water. The importance of tides has also been discussed. These effects must be taken into consideration when planning to utilize these water sources for irrigation.

Brackish water has a great potential for use as irrigation water. In the past, owing to lack of information, some injury has been caused where waters too high in salt concentration have been used on low salt-tolerant crops.

In several instances farmers have used brackish water without injury and have benefited by its use. In April 1959 a field of about 30 acres of cauliflower was irrigated with brackish water in Currituck County, North Carolina. At the time brackish water was applied, the cauliflower was wilting. The water available for irrigation from Albemarle Sound had an EC value of 5.25 mmhos per cm. Since cauliflower was listed in the medium salt-tolerant group of crops, it was suggested the farmer apply initially a 1½-inch application of this water. The soil was predominantly Lakeland and Klej deep loamy fine sands. During the period March 8 through July 1, from the best information available, the farmer applied a total of approximately 8 inches of water. During this period no rainfall was recorded. A normal crop was harvested during the latter part of June, and there were no visual signs of damage or depression of growth. The salt accumulated in the soil was subsequently leached out by summer rains. Although this was not a replicated experiment, it is indicative of the potential value of these water sources. In other areas, brackish water has been used successfully for irrigating snap beans, gladioli, alfalfa, and tomatoes.

Investigations are in progress to determine the soil-plant-water relationships associated with the use of brackish water and to develop the necessary criteria for its safe utilization. In this manner, it is hoped that a large supply of water will be made available for agricultural utilization.

APPENDIX

TABLE 7.—*Analyses of water samples from the Eastern Shore of Virginia*

Sampling date	Sample depth (ft.)	pH	EC (mmhos/cm.)	SAR	Ionic composition (meq./l.)						
					Ca++	Mg++	Na+	K+	Cl-	HCO3-	SO4-
					Beasley pond						
1957	1	6.61	5.00	13.50	3.30	9.10	33.60	1.00	39.20	—	—
1957	3	7.00	21.00	30.90	7.40	33.60	140.00	3.50	170.00	—	—
1958	1	7.80	.41	.70	1.90	.49	.96	.15	1.33	0.52	0.99
1958	3	7.85	.40	.90	1.89	.43	.97	.15	1.32	.56	.99
1958	1	6.50	12.00	22.80	6.20	18.00	79.50	1.83	90.66	.98	13.70
1958	3	6.52	19.00	29.20	8.72	29.08	127.00	2.75	145.40	1.80	20.40
1959	1	7.02	.90	2.70	2.60	1.50	3.85	.21	4.88	.82	1.94
1959	1	7.01	.70	2.30	2.23	1.38	3.03	.24	3.31	2.69	.88
					Fitchette pond						
1957	1	4.92	0.90	1.60	1.99	2.49	2.46	0.20	3.68	—	—
1957	4	4.92	.91	2.20	1.97	2.56	3.28	.25	4.12	—	—
1958	1	7.03	.45	.81	1.49	1.44	.97	.08	1.22	0.55	2.14
1958	4	6.98	.44	.81	1.49	1.46	.97	.09	1.25	.54	2.11
1958	1	7.49	.59	1.50	1.47	1.87	1.95	.15	2.31	1.04	
1958	4	7.33	.59	1.60	1.93	1.90	2.00	.16	2.31	1.06	
1959	1	6.64	.68	1.50	1.93	2.21	2.12	.13	2.57	.74	3.03
1959	1	6.92	8.90	26.80	5.36	17.67	8.30	1.80	91.00	1.54	3.20
					Ames pond						
1959	1	6.63	6.90	18.50	3.94	12.58	53.00	1.18	61.90	0.58	8.30
1959	4	6.51	7.00	18.40	4.28	13.14	54.30	1.20	63.60	.86	8.80
1959	1	6.78	12.00	38.20	8.09	25.14	113.00	2.30	127.00	2.75	19.40
1959	1	7.46	14.00	26.40	7.98	27.32	113.50	3.45	137.20	2.40	14.30

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Table 8.—*Chemical analysis of water samples from the Eastern Shore of Virginia (July 16, 1958)*

Location	pH	EC (mmhos/cm.)	SAR	Ionic composition (meq./l.)						
				Ca^{++}	Mg^{++}	Na^+	K^+	Cl^-	HCO_3^-	SO_4^-
Jones Bros. Creek	7.08	35.00	44.00	10.60	55.20	252.00	5.60	290.00	2.16	31.70
Guilford Creek	6.80	.20	---	.68	.52	.62	.05	.64	.53	.68
Jenkins Bros. Creek	6.99	7.75	21.80	3.03	13.67	63.00	1.40	73.15	1.50	6.36
Bullbeggar Marsh	6.70	6.90	20.40	2.38	12.12	55.00	1.30	64.60	1.22	5.52
Bullbeggar Road Bridge	6.59	4.65	18.20	1.77	8.15	40.50	.90	46.08	1.70	2.14
Mosquito Creek	7.73	31.50	42.90	9.70	51.80	238.00	5.00	272.00	2.15	29.90
Mosquito Creek	6.62	.21	---	.75	.52	.66	.03	.68	.70	.46

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TABLE 9.—*Chemical analysis of water samples from Charleston, S.C.*

Date and location	pH	EC (mmhos/cm.)	SAR	Ionic composition (meq./l.)						
				Ca++	Mg++	Na+	K+	Cl-	HCO3-	SO4=
May 29, 1958:										
Wallace Creek	7.54	32.00	41.80	10.00	48.25	225.00	4.80	251.25	1.80	----
Toogoodoo River	7.76	35.50	43.00	12.00	57.50	254.00	5.60	301.25	2.18	----
Dowhoo River	7.16	4.90	15.20	1.75	6.55	31.00	.90	34.65	.79	----
Johns Island bridge	7.75	31.90	42.30	10.00	50.25	231.00	4.90	260.00	5.08	----
Church Creek	7.85	37.00	44.20	11.50	57.75	260.00	5.60	300.00	2.12	----
Stono River bridge	7.59	28.50	39.50	9.50	44.25	204.00	4.50	231.25	1.95	----
Nov. 30, 1958:										
Wallace Creek	7.23	----	55.80	20.79	90.21	415.50	9.20	482.60	2.44	49.40
Toogoodoo River	7.20	----	55.00	19.32	96.28	426.00	9.40	494.00	2.52	53.60
Dowhoo River	7.11	----	51.40	18.69	76.91	355.00	8.00	418.00	2.15	42.40
Johns Island bridge	7.10	----	56.30	18.90	92.90	420.00	9.30	486.40	2.47	50.20
Church Creek	7.18	----	56.80	19.53	96.27	432.00	9.60	501.60	2.66	52.80
Stono River bridge	7.20	----	50.30	14.91	74.49	336.00	7.45	389.50	2.08	40.60

TABLE 10.—*Chemical composition of water samples from rivers and streams in the vicinity of Bridgeton, N.J.*

Date and location	Site No.	pH	EC (mmhos/cm.)	SAR	Ca++	Mg++	Na+	K+	Cl-	HCO3-	SO4=
June 1958:											
Cohansey River	1	6.60	2.90	12.10	1.18	4.50	20.30	0.51	23.30	1.00	2.72
Cohansey River	2	6.70	8.40	21.90	3.04	14.80	65.00	1.40	79.00	1.40	5.15
Maurice River	1	6.29	2.18	11.40	.84	3.69	17.00	.45	18.53	.38	2.20
Maurice River	2	6.18	2.24	2.40	.23	.37	1.30	.05	1.52	.16	.46
Dividing Creek	1	6.53	8.00	20.70	2.68	13.84	59.50	1.20	72.50	.98	7.22
Dividing Creek	2	6.40	5.20	16.90	1.72	8.64	38.50	.85	48.00	.80	4.46
Nantuxant River	1	6.79	22.00	31.70	5.70	30.50	135.00	3.30	166.00	3.00	15.72
Nantuxant River	2	6.82	21.00	31.70	5.60	30.60	135.00	2.90	164.00	2.50	15.84
December 1958:											
Cohansey River	1	6.13	2.75	9.55	1.43	4.19	19.00	.50	21.09	.62	2.68
Cohansey River	2	6.33	10.00	24.20	4.73	18.07	82.00	1.90	95.00	.77	11.00
Maurice River	1	6.12	2.80	11.90	1.20	4.22	19.50	.47	22.42	.36	2.54
Maurice River	2	6.12	.10	1.20	.23	.25	.81	.06	.80	.10	.40
Dividing Creek	1	6.38	4.75	15.05	1.73	6.79	31.00	.70	36.10	.42	3.88
Dividing Creek	2	6.12	1.82	10.70	.77	2.63	12.25	.30	13.73	.41	1.58
Nantuxant River	1	6.66	24.00	35.80	7.77	36.63	168.00	3.60	190.00	1.61	24.20
Nantuxant River	2	6.50	1.06	6.90	.62	1.53	7.20	.21	7.35	.20	2.06
September 1959:											
Cohansey River	1	6.50	6.25	20.20	3.68	10.06	53.00	1.18	60.76	.81	6.00
Cohansey River	2	6.62	26.50	39.80	9.14	44.59	206.00	4.40	238.14	1.14	25.20
Maurice River	1	6.46	5.48	18.80	3.26	7.65	44.00	.92	50.17	.45	4.76
Maurice River	2	6.52	.68	6.10	.45	.80	4.80	.14	5.37	.10	.61
Dividing Creek	1	6.56	11.00	26.60	4.73	22.24	97.50	2.10	114.00	.63	11.80
Dividing Creek	2	6.51	7.50	22.00	3.68	13.69	64.50	1.42	75.46	.57	7.20
Nantuxant River	1	6.80	30.00	43.70	9.66	47.10	232.00	4.90	267.80	1.96	23.80
Nantuxant River	2	6.40	1.23	------	.72	1.67	8.60	.25	10.00	.20	1.00
March 1960:											
Cohansey River	1	6.56	5.25	16.30	2.11	9.89	40.00	.90	44.69	.63	6.10
Maurice River	1	6.33	5.02	16.50	1.76	9.04	38.50	.90	43.41	.21	4.70
Dividing Creek	1	6.39	6.40	17.70	2.17	12.73	49.50	1.05	55.27	.46	7.90
Nantuxant River	1	6.60	5.68	20.10	2.43	21.07	53.80	1.10	59.58	.64	6.70

TABLE 11.—*Analysis of water samples from brackish water ponds in the vicinity of Bridgeton, N.J.*

Location	Date	Sample depth (ft.)	pH	EC (mmhos/cm.)	SAR	Ionic composition (meq./l.)						
						Ca++	Mg++	Na+	K+	Cl-	HCO3-	SO4-
Dix Bros	9/57	1	5.36	23.90	32.30	6.80	38.00	153.00	3.20	175.00	--	--
	9/57	4	6.85	35.00	45.80	9.00	55.40	260.00	5.20	279.00	--	--
	10/57	1	4.46	27.90	34.10	14.00	45.20	185.00	3.20	216.00	--	--
	10/57	4	6.15	36.00	39.10	13.20	68.60	250.00	3.70	285.00	--	--
	4/58	1	6.54	4.40	14.10	1.53	7.27	30.00	.67	36.50	0.73	--
	4/58	4	6.68	4.25	14.30	1.83	7.25	30.50	.66	36.40	.60	--
	11/58	1	6.38	4.30	25.80	5.57	21.03	94.00	1.80	105.50	1.67	15.40
	11/58	4	6.41	14.70	26.20	6.72	21.08	97.00	1.80	110.00	1.63	15.40
	4/59	1	6.53	5.50	16.50	5.63	7.34	42.00	.88	48.76	1.17	6.00
	4/59	4	6.46	5.10	17.00	5.78	7.62	44.00	.92	51.62	1.11	6.00
	8/59	1	6.62	5.02	25.90	2.98	9.87	41.00	.61	48.99	1.99	3.20
	8/59	4	6.43	6.60	21.70	2.56	11.18	57.00	1.17	62.88	1.91	5.60
	11/59	1	6.59	6.50	16.60	5.46	11.94	48.00	.92	59.58	1.50	6.00
	11/59	4	6.60	12.50	27.09	7.46	25.04	110.00	3.10	132.28	1.46	13.20
	3/60	1	6.64	13.30	24.40	4.26	20.34	87.50	1.52	96.82	1.50	12.00
	3/60	4	6.93	17.80	27.80	5.57	28.13	118.00	1.52	130.34	3.21	13.60
N. Bowker	9/57	1	3.35	7.60	17.70	2.40	12.80	49.00	1.13	75.00	--	--
	9/57	4	5.36	7.50	18.00	2.40	13.00	50.00	1.11	75.00	--	--
	10/57	1	3.51	8.25	20.40	2.20	15.00	60.00	1.20	83.00	--	--
	10/57	4	3.49	8.25	20.30	2.10	14.90	59.00	1.22	85.00	--	--
	4/58	1	3.86	3.80	13.70	1.53	5.75	26.20	.43	31.90	.25	--
	4/58	4	3.89	3.80	13.70	1.55	5.75	26.20	.43	32.50	.10	--
	11/58	1	3.66	2.35	10.23	1.16	3.20	15.25	.29	17.10	0	2.74
	11/58	4	3.67	2.30	10.39	1.11	3.21	15.25	.29	17.50	0	2.48
	4/59	1	3.73	1.99	8.50	.89	2.88	12.20	.24	14.95	0	2.42
	4/59	4	3.76	1.85	8.30	.94	2.76	12.20	.23		0	1.82
	8/59	1	6.88	1.38	8.40	1.32	2.91	8.80	.18	10.30	.98	1.64
	8/59	4	4.30	1.30	8.40	.89	2.02	8.80	.18	10.10	.18	1.58
	11/59	1	4.02	1.36	7.30	1.05	1.86	8.80	.27	10.58	0	1.57
	11/59	4	3.92	1.33	7.40	1.01	1.85	8.90	.26	10.68	0	
Perry Bros	8/59	1	6.13	1.83	14.20	1.01	2.81	12.80	.35	15.15	.48	1.50
	4/59	1	6.07	.88	--	.78	1.39	5.40	.18	6.02	.29	1.24
	11/59	1	6.38	1.28	6.90	.88	1.92	8.20	.32	9.60	.36	1.17

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TABLE 12.—*Analysis of water samples in the vicinity of Currituck, N.C.*

Date and location	pH	EC (mmhos/cm.)	SAR	Ionic composition (meq./l.)						
				Ca^{++}	Mg^{++}	Na^+	K^+	Cl^-	HCO_3^-	SO_4^-
May 1958:										
Tice Bros. ditch	6.60	0.20	1.90	0.34	0.32	1.11	0.06	1.15	0.35	---
Currituck Sound	6.48	.48	3.70	.46	.66	2.75	.09	2.95	.36	---
Albemarle Sound	7.03	1.10	7.50	.54	1.89	8.30	.21	9.57	.48	---
Point Harbor	7.01	1.65	8.13	.71	2.35	10.40	.25	11.90	.67	---
December 1958:										
Tice Bros. ditch	6.52	.48	3.50	.59	.63	2.70	.12	3.23	.32	0.54
Currituck Sound	6.98	1.00	5.80	.76	1.28	5.90	.21	6.71	.35	1.14
Albemarle Sound	6.88	5.02	16.30	2.02	8.24	38.75	.87	44.89	.36	4.72
Point Harbor	7.03	6.00	19.30	2.08	10.37	46.00	1.10	52.96	.50	5.84
April 1959:										
Tice Bros. ditch	6.15	.60	4.50	.61	.81	3.80	.16	4.20	.53	.71
Currituck Sound	6.40	1.08	6.60	.72	1.46	6.90	.53	8.06	.24	1.18
Albemarle Sound	6.11	2.95	9.90	1.03	4.66	20.75	.48	23.74	.30	2.74
Point Harbor	6.69	6.75	19.30	2.44	12.16	53.00	1.20	62.50	.52	6.60
August 1959:										
Tice Bros. ditch	6.30	1.32	5.20	.84	1.97	9.40	.23	10.45	.64	1.25
Albemarle Sound	6.05	2.85	12.80	.81	4.62	21.40	.50	24.23	.25	2.62
Point Harbor	6.37	5.20	17.10	1.77	8.92	40.50	.90	46.17	.42	5.00
November 1960:										
Currituck Sound	6.42	2.20	10.20	1.00	3.40	15.20	.47	18.23	.40	1.75
Albemarle Sound	6.70	4.45	15.50	1.51	7.69	33.20	1.05	39.59	.36	3.50
Point Harbor	6.70	6.10	14.10	2.06	10.86	48.00	1.30	56.84	.55	4.80